APPENDIX D
VALLEY AND FLOODPLAIN MORPHOLOGY ANALYSIS

D.1 INTRODUCTION

Floodplain and river ecosystems are dynamic mosaics that adjust over time to local and watershed-level changes in discharge, sediment delivery, debris inputs, and riparian vegetation conditions. Valley morphology influences channel and floodplain conditions according to valley bottom width, slope, and valley wall interaction with the channel. Narrow valley bottoms constrict the floodplain-river environment, while broader valley bottoms permit floodplain building and lateral channel migration. Valley bottom or floodplain slope in part affects channel and floodplain morphology by influencing stream energy. Higher gradient floodplains are typically associated with greater stream energy and straighter channel planforms. Flatter floodplain gradients generally support more sinuous, lower energy channel types. A continuum of channel types exist between the higher energy (braided planform) and lower energy (meandering planform) morphological endpoints (Leopold and Wolman, 1957; Van den Berg, 1995; Millar, 2000). Intermediate channel types, include anabranching or anastomosing channels, are defined by multiple channels separated by stable vegetated islands (Nanson and Knighton, 1996; Millar, 2000; Tooth and Nanson, 2004). Although floodplain gradient has an important influence on channel pattern, other controlling variables include discharge, sediment particle size distribution, and riparian vegetation condition. Valley wall interaction with the river also influences channel pattern via sediment delivery, sediment transport efficiency, and channel scour. Floodplain buffers separating a channel from the adjacent valley wall may also influence sediment transport and storage, flood water conveyance, and channel stability. Valley morphology influence on the floodplain-river environment affects channel morphology. These relationships in the Clark Fork River (CFR) and Blackfoot River (BFR) watersheds were investigated to characterize the role of valley morphology on floodplain-channel processes.

The historical floodplain-river environment in the CFR and BFR restoration project area has been an area of focus since the Draft Conceptual Restoration Plan (DCRP) was completed in 2003 (Water Consulting, Inc. and Wildland Hydrology). Identifying the influence of valley morphology on the floodplain and river environments was a priority task for the Phase 2 Restoration Plan (RP). Because the lower BFR is confined by a narrow valley bottom and has a minimal floodplain width, the current channel alignment resembles its historical location. Conversely, the CFR with a wider valley bottom and more extensive floodplain has a greater potential for lateral channel migration and a wider range of channel types. Historical and contemporary land management practices, the transportation corridor, and Milltown Dam have altered the CFR throughout the watershed and more specifically, within the restoration area. Phase 2 data collection efforts were directed to characterize the likely historical river corridor conditions, evaluate the existing corridor conditions, and to develop design parameters for the CFR restoration in the restoration project area. Four questions were presented in planning the Phase 2 data collection.

1. What were the most likely historical CFR valley, floodplain, and channel conditions prior to European-American settlement in the 1850s?
2. How have the valley, floodplain, and channel conditions been altered since the 1850s, and what mechanisms are responsible for spatial and temporal river and floodplain changes?
3. What are the constraints and limitations that the restoration plan must consider?
4. What are the desired channel and floodplain morphologies given the existing conditions and restoration project area constraints?

The following report presents information that addresses these four questions. The analysis is based on field data and aerial photograph interpretation for reaches on the CFR and BFR. An additional analysis also investigated channel planforms related to river confluences in western Montana.

D.2 METHODS

Phase 2 methods used to evaluate historical, existing, and potential river corridor conditions included review of historical maps and documents, field data collection and aerial photograph interpretation of the CFR and BFR, and aerial photograph interpretation of other river confluences in western Montana. The following section presents these techniques.

D.2.1 Historical Narratives and Maps

Reviewed historical narratives spanned from when the Lewis and Clark Expedition explored the area in 1805-1806, to passages recorded by Milltown Dam's operators who protected the structure during the 1908 flood of record. Detailed journals, correspondence, and maps from the Northern Pacific Railroad (NPR) survey (1853 to 1854), and later the Military Road survey and construction (1856 to 1861), provided insights to the CFR and BFR river corridor conditions prior to widespread resource extraction and development. However, even by the early 1860s mining in the CFR headwaters had begun to affect river processes. Expedition leaders including Captain Meriweather Lewis (Corps of Discovery), Governor Isaac Stevens (NPR survey), and Lieutenant John Mullan (Military Road survey) recorded extensive notes concerning their operations. Subordinate personnel including Dr. George Suckley (NPR survey), and Theodore Kolecki and P.M. Engle (Military Road survey) also authored correspondence and illustrations characterizing the CFR watershed. Historical narratives were primarily reviewed for the purpose of evaluating the historical conditions of the CFR and BFR in the restoration project area as well as the CFR watershed as a whole.

Maps dating to the Lewis and Clark Expedition were reviewed to evaluate river corridor conditions in the restoration project area. Although maps varied in scale and detail, several maps were useful for characterizing the CFR. Survey maps drawn by the Stevens and Mullan expeditions were completed to determine possible routes for the railroad and military road, respectively. An 1862 map completed by the Mullan Expedition illustrated a dynamic CFR at present-day Turah. Later maps surveyed by the General Land Office (GLO) (1880s) and the U.S. Geological Survey (USGS) (1903) provided differing interpretations of the CFR channel

planform through the restoration project area. The GLO map characterized the channel as a single thread river where as the later USGS map depicted the CFR upstream of the confluence as a multiple channel (anabranching) system. Survey maps completed after 1908 and the first aerial photographs taken in 1937, captured the CFR following the flood of record in addition to the effects of 50 years of extractive land uses and development throughout the watershed. Early maps of the CFR and BFR provide insights to the historical conditions of the river corridors. Reviewed maps suggest portions of the CFR may have maintained multiple channels while other reaches were characterized by a single thread meandering channel.

D.2.2 Valley Morphology Classification

Although the reviewed historical information provided an adequate picture of the watershed conditions prior to the modern era (established as the 1940s), modern techniques were also used to evaluate valley and floodplain morphologies. River systems are shaped by the valley in which they drain. Valley morphology has an over-riding influence on floodplain composition and channel morphology. To further investigate this area, we employed a valley morphology classification system (Rosgen, 1996). The selected valley classification system is hierarchical, meaning the identification of a valley's morphology, or type, can provide the basis for predicting channel morphology. Because channel types (e.g. meandering, anabranching, or braided) tend to be associated with specific valley morphologies, the valley classification permits a level of channel type prediction based on valley characteristics.

The intent of the valley classification is to predict the likely historical channel planform based on valley morphology. Additionally, understanding the existing valley morphology and valley-channel interactions will be an essential element in the restoration project area design to be further investigated in Phase 3.

D.2.4 Time Series Aerial Photograph Interpretation

An historical planform geometry analysis was completed for the CFR near Milltown Dam. The upstream and downstream boundaries of the analysis area were Turah Bridge, and the upstream-most influence of the reservoir varial zone, respectively. Six aerial photograph series were reviewed including photos from 1937, 1956, 1966, 2000, 2003, and 2004 (see Appendix E for the aerial photographs and channel traces). However, only four time series covered the entire analysis area: 1937, 1956, 1966, and 2000. Existing channel and floodplain morphology in the CFR study reach were compared to remnant channel segments identified in the 1937 air photos; to an upstream section of CFR near Clinton, Montana; and to the BFR Ovando C reach. The intent of this analysis is to evaluate historical and existing channel patterns and to determine how the CFR has changed over time. Additionally, planform dimensions will be used for developing the restoration treatments for the restoration project area (see Appendix H).

Since impacts were well-established by the 1937 air photo series, a traditional meander geometry analysis (Langbein and Leopold, 1966; Thorne, 1997) was deemed unfeasible. For example, portions of the mainstem CFR were entrenched against either the highway or railroad grades, limiting the lateral extent of meander migration. Other reaches exhibited a braided channel planform. A small percentage of the active planform displayed measurable, single thread

meanders. As a result, conventional indices such as meander wavelength and meander radius of curvature were not practical as assessment tools for the majority of the reach. However, interpretation of historical meander belt width and channel sinuosity was possible based on the measurement of remnant channel forms on the floodplain. Additionally, the CFR3-B reference reach was evaluated as a planform geometry reference condition as the reach has remained relatively stable through the time series. Remnant channel segments outside of the CFR upstream study reach, in the vicinity of Clinton were also quantified.

D.2.4.1 Channel Planform Measurement Methods

Meander belt width is defined as the active meander corridor. For meandering channels, the belt width is measured from the apex of the meander, across the channel, to the boundary formed by the line drawn between the upstream and downstream meanders. For braided planforms, the belt width corresponds to the lateral limits of the floodway that contains all dominant and subsidiary channels. For straight channels (sinuosity ≤ 1.5 (Wolman and Leopold, 1957), the belt width essentially replicates the bankfull channel width.

The meander belt width was defined on the 1937, 1956, 1966, and 2000 air photos. In an effort to randomize measurement locations, sites were identified that correspond to 500 ft increments on the longitudinal profile. The longitudinal grid was superimposed on each time series and occupied the exact geographical locations from series to series.

D.2.4.2 Meander Geometry Reference Conditions Methods

Dimensionless ratios were produced for the planform geometry variables including meander wavelength, meander belt width, and radius of curvature. Dimensionless ratios are produced by dividing the meander geometry variable by the bankfull channel width. Ratios allow size-independent comparisons of different river reaches. An analysis was completed comparing the CFR study reach captured in 1937 and 2004, the Clinton reach, and the BFR Ovando C reach. A bankfull channel width of 137 ft was used to calculate the meander geometry dimensionless ratios for active and relict channels found in the 1937 and 2004 photos. A bankfull channel width of 160 ft was used to calculate the planform geometry for the Clinton reach and the BFR Ovando C reach.

D.2.5 Comparison of the CFR-BFR Confluence to Other River Confluences in Western Montana

River confluences are generally complex, with many fluvial and hydraulic processes occurring during different seasons and flood events. An analysis of five western Montana river confluences that are similar to the CFR near Milltown Dam was completed to evaluate the frequency of channel braiding associated with regional river confluences. The confluences studied include the following rivers.

- The CFR/Rock Creek confluence near Clinton, Montana.
- The CFR/Flathead River confluence near Paradise, Montana.
- The CFR/Bitterroot confluence near Missoula, Montana.
- The BFR/North Fork BFR confluence near Ovando, Montana.

- The North Fork Flathead River/Middle Fork Flathead River confluence near Columbia Falls, Montana.

D.2.6 BFR Floodplain Transition Analysis

A floodplain and channel morphology analysis was completed to better understand how valley, floodplain, and channel morphologies interact through a valley transition reach. The Ovando reach was selected as an analog for the historical CFR valley transition that occurred through the reservoir reach prior to the construction of Milltown Dam. As with the CFR in the restoration project area, the Ovando reach progresses from an unconfined valley (Valley Type VIII), to a moderately confined valley, to a structurally controlled system (Valley Type II). Through this valley morphology succession, the BFR transitions from a C stream type, to a B stream type, and finally to a confined F stream type. The historical CFR is believed to have followed a similar succession as the river transitioned from a C stream type upstream from the Duck Bridge, to a B stream type in the vicinity of the confluence, and finally to a F stream type downstream from the present-day BNSF bridge. The CFR remained confined through the Bandmann Flats area to Missoula.

In 2004 an extensive hydrologic survey was completed to characterize the floodplain and channel in the BFR Ovando reach. The survey consisted of 33 cross-sections over 14,400 ft of valley distance to characterize the valley transition (see Figure E-11). Ten valley transects characterized the floodplain to an elevation two times the maximum riffle depth (the floodprone elevation is expected to contain moderate magnitude, relatively low frequency floods approximated at less than a 50 year recurrence interval event (Rosgen, 1996)). Within several cross-sections, the floodprone elevations corresponded to a floodplain feature, such as a terrace or slope break. At points between surveyed cross-sections or where the cross-sections were widely spaced, floodplain features identified on the aerial photograph were used to define the floodprone extent.

Field data were processed and overlain on the aerial photograph of the study area using GIS. Various analyses were completed to compare floodplain and channel characteristics through the valley transition. The intent of this task was to evaluate the channel dimensions, profile, and planform; channel bed sediment characteristics; and floodplain morphology through the transition and use the results in preparing the CFR design for the restoration project area.

D.3 RESULTS

The following sections present the results from the data collection that was completed to characterize the historical, existing, and desired future conditions for the CFR restoration area valley and floodplain morphologies. The first three sections provide an overview of CFR river corridor conditions spanning from the early 1800s to present. The fourth section presents information on valley morphology and the role of valley morphology in determining channel planform. The aerial photograph interpretation results follow. The last two sections present the river confluence evaluation results and the BFR valley transition information.

D.3.1 Historical River Corridor Conditions: Pre-European American Settlement

Journals, field notes, and sketches of the river corridor that were completed by explorers that traversed the region beginning in 1805 with the Lewis and Clark Expedition were reviewed. Traveling through the confluence area in 1805 and again in 1806, Captain Meriweather noted river corridor conditions as the Corps of Discovery progressed up the CFR. Upon encountering the CFR-BFR confluence area in early July 1806, Lewis remarked (Moulton, 1993b, p. 88):

> *The first 5 miles of our rout was through a part of the extensive plain in which we were encamped, we then entered the mountains with the East fork of Clark's river* [Clark Fork River] *through a narrow confined pass on it's N. side continuing up that river five ms. further to the entrance of the Cokahlahishkit R* [Blackfoot River] *which falls in on the N.E. side, is 60 yds. wide deep and rapid. the banks bold not very high but never overflow. the East fork below its junction with this stream is 100 yds. wide and above it about 90. the water of boath are terbid but the East branch much the most so; their beds are composed of sand and gravel; the East fork possesses a large portion of the former. neither of those streams are navigable in consequence of the rapids and shoals which obstruct their currents. Thus far a plain or untimbered country bordered the river which near the junction of these streams spread into a handsome level plain of no great extent; the hills were covered with long leafed pine and fir.*

Lewis' observations suggest both the CFR and BFR were dominated by shallow rapids in the vicinity of the confluence of the two streams. The untimbered plain at the junction of the two rivers refers to the rivers' floodplain that was likely vegetated with willows, shrubs, and forbs.

Following the Corps of Discovery, fur trappers and settlers moved through the area. Trapper and geographer David Thompson traveled throughout the region, but did not survey the CFR and BFR in the restoration project area. Father Jean-Pierre DeSmet, a Jesuit missionary who established the St. Mary's mission near present-day Stevensville, Montana, recorded the conditions of the Bitterroot and Clark Fork valleys in the 1840s. Father DeSmet noted (*cited in* Hortsman, 1984):

> *…the country is well watered, for it abounds with small lakes and rivulets, and is surrounded by mountains, at whose base are found numberless springs. In no part of the world is the water more limpid or pure, for whatever may be the depth of the rivers, the bottom is seen as if there were nothing to intercept the view.*

D.3.2 Historical River Corridor Conditions: 1850s to 1940

Gold was first discovered in Gold Creek near present-day Garrison Junction in 1852, and by the 1860s nearly every stream within the Gold Creek watershed was actively prospected. An 1863 map produced by the Mullan Expedition (Kolecki, 1863) noted gold mining in the Gold Creek drainage down-valley from La Barge City, the first town encountered upon entering the Deer Lodge Valley from the west. Placer mining was quickly replaced by hydraulic mining as the most efficient method for washing gold from streambeds and hillsides. Mining waste was discharged directly to the stream network and ultimately to the CFR (*cited in* Hortsman, 1984).

The NPPR survey, led by Washington Governor Isaac I. Stevens, surveyed the region to determine the best location for a railway along the 47th parallel. Stevens' expedition was well staffed with both Army regulars and scientific personnel including naturalists, engineers, topographers, astronomers, and physicians (Goetzmann, 1959). Artists were also detailed to illustrate the landscapes that were encountered on the expedition (Warren, 1859). Referring to the CFR, Stevens commented on the sizeable watershed and the contribution of flow to the Bitterroot River, which at the time was considered to extend to the confluence of the Flathead River (Stevens, 1856).

> *Hell-Gate* [Clark Fork River] *is the debouche of all the considerable streams which flow into the Bitter Root, eighty-five miles below its source at the Big Hole divide. The distance from Hell-Gate to its junction with the Bitter Root is fifteen miles. It must not be understood from the term Hell-Gate that here is a narrow passage with perpendicular bluffs; on the contrary, it is a wide, open, and easy pass, in no case being less than half a mile wide, and the banks not subject to overflow at all. At Hell-Gate is the junction of two streams; the one being the Hell-Gate river and the other the Big Blackfoot river.*

The Mullan expedition established a camp at the CFR-BFR confluence in the winter of 1860 and 1861 during the construction of the Military Road. The Military Road (later called the Mullan Road) was to link Fort Walla Walla on the Columbia River, with Fort Benton on the Missouri River at distance of 640 miles. Reaching Cantonment Wright at the CFR-BFR confluence on November 22, 1860, Mullan divided his men into five groups. The first group remained at the confluence to construct a bridge over the BFR near the confluence (Figure D-1). The other groups were distributed in winter camps along the CFR from present-day Turah to Beavertail Rock (Kolecki, 1863) at locations where hill slope cuts were to be made in an effort to minimize the number of necessary river crossings (Mullan, 1863).

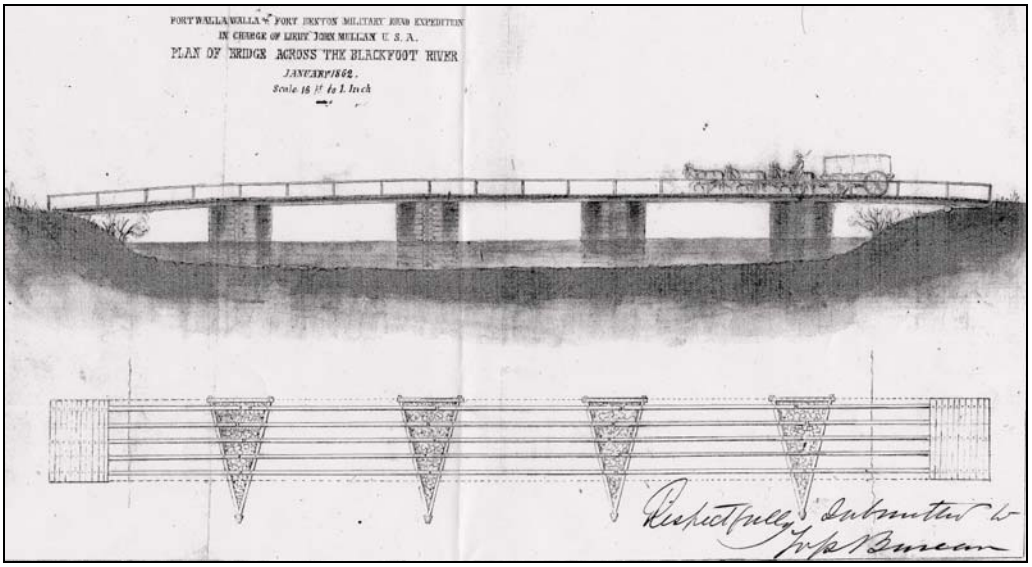
FORT WALLA WALLA & FORT BENTON MILITARY ROAD EXPEDITION
IN CHARGE OF LIEUT JOHN MULLAN U S A.
PLAN OF BRIDGE ACROSS THE BLACKFOOT RIVER
JANUARY 1862.
Scale 16 ft to 1 Inch
Respectfully Submitted by
Wm P Bureau

Figure D-1. The Military Road crossing on the Blackfoot River drawn under the guidance of Lieutenant John Mullan in 1862. Image provided by the National Archives (File: RG 77 Rds. 174-6).

Construction of the Military Road impacted the CFR and BFR in addition to the many CFR tributary streams that were crossed. Timber removal, blasting of rocky outcrops, and stream and floodplain modifications were necessary to make the road passable for early miners, homesteaders, and other travelers. Although Mullan limited the number of crossings of the CFR, tributary stream crossings and road sections on the CFR floodplain typically necessitated corduroying wetland areas that were too soft for wagon travel. Mullan noted while in the Deer Lodge Valley, "I examined the side hills with a view of making a high water road, avoiding this and the next crossing. It will require 5,000 feet of heavy grading, part in rock, and 130 feet of corduroying to avoid marshy ground," (Mullan, 1861).

Following the survey of the 47th parallel and the completion of the Military Road, construction of the NPR was completed in 1883. Ten bridges crossed the CFR between Garrison Junction and Missoula. To shorten the railroad and increase railway safety, the CFR was re-routed at two locations. Two channels were excavated and the historical channel was abandoned by the railroad grade. The abandoned channels were diked with debris piles, brush, and rocks to disconnect the channels from the river corridor. A competing railroad, the Chicago, Milwaukee and St. Paul Railway (CMSPR) was constructed along the southern boundary of the channel alignment. The competing line was completed before the flood of 1908 which washed away 75 miles of newly laid track (*cited in* Hortsman, 1984).

The first agricultural activities in the upper CFR were established in the 1850s as settlers moved into the watershed. Ranches in the Deer Lodge Valley, what would become the Missoula Valley, and the Clark Fork Valley in the vicinity of present-day Frenchtown, used the numerous streams for irrigation and capitalized on the high quality range for grazing. Sheep and cattle grazed riparian zones and upland areas were sold by settlers to sustain the mining camps that had become established in the Gold Creek drainage.

As mining claims grew throughout the CFR headwaters, logging operations emerged to provide the mines with wood for mine timbers, fuel, and other infrastructure. The first log drive down the BFR in 1886 delivered 20 million board feet of timber to the mill at Bonner. Logged-over areas were converted from forest to agriculture as farmers took advantage of the cleared forests. Riparian and upland trees were also cleared to provide fuel and building materials for developing towns such as Missoula, Bonner, and Butte.

Rapid resource development in the CFR watershed altered the environment that Lewis and Clark had encountered seventy years. In 1872, James A. Garfield, later a U.S. President, after traveling down the CFR in wrote in his diary, "The beautiful river has been permanently ruined by the miners; and has been for three years as muddy as the Missouri. Before the discovery of gold, it was as clear and pure as any mountain stream could well be" (*cited in* Hortsman, 1984).

With the completion of the Military Road and the railways, an increasing number of immigrants settled in the CFR valley. By 1903, the transportation corridor included a county road (Mullan Road) and the NPR. The USGS 1903 depicts a bridge crossing the CFR upstream from the confluence and near Bonner (Figure D-3). A second bridge spanned a CFR sidechannel and provided access to a homestead at the mouth of Deer Creek. It is not known how long these two bridges remained in-place, although it is likely they were destroyed by the 1908 flood.

The CMSPR railway, completed shortly before the 1908 flood, included a bridge across the CFR to connect to the NPR on the north side of the valley at Bonner. Referred to as the Duck Bridge, the bridge was operational through the late 1970s. By 2000, the bridge deck had been removed and the bridge dismantled. The Duck Bridge rail grade is the most profound floodplain constriction, within the CFR restoration project area. The remaining grade fill reduces the CFR floodplain width to 600 ft to 650 ft, approximately 22 percent of the historical floodplain width at that location. Since the Duck Bridge pre-dates both the construction of Milltown Dam and the flood of 1908, the Duck Bridge influenced flood hydraulics and sediment storage in the reach.

Milltown Dam was completed in early January, 1908 at the CFR-BFR confluence. The dam was constructed to supply power to Missoula and to lumber mills in Milltown. An electric trolley was later built to provide transportation between Missoula and Bonner. Constructed at the floodplain constriction created by the encroaching Sapphire Mountains from the south and a glacial terrace to the north, Milltown Dam modified physical, chemical, and biological processes of the two rivers. The dam effectively severed the fluvial system and altered the CFR upstream and downstream of the dam. The dam also created a depositional reach in the CFR restoration project area and the Remediation Project Area. The low-energy backwater has affected an increasing area upstream of the dam. Sediment deposited by periodic large floods at the upper extent of the backwater, has increased the area of deposition in an upstream direction, further impacting the CFR outside of the immediate reservoir area.

The 1908 flood, estimated at 48,000 cfs downstream from Milltown Dam, was the flood of record on the CFR. The 400 to 500-year recurrence interval event destroyed all of the bridges through Missoula and severely impacted Milltown Dam. In an attempt to save the dam, the crib-work at the southern extent of the dam was blown with dynamite. Dam operators estimated the flow velocity at 20 miles per hour following the dynamiting of the structure, as the river rapidly drained through the void (*cited in* Missoulian, 2002).

Construction of the state highway, the railways, and Milltown Dam, in addition to the extensive resource extraction throughout the watershed, primed the CFR for the 1908 flood. With suspected increased sediment delivery to the channel network from headwater mining, logging, and regional grazing, the CFR was incapable of routing the flow and sediment load of the high magnitude flood. The constricted floodplain combined with transportation corridor-related channelization increased stream power and sediment mobilization throughout the watershed. An estimated 6.6 million cubic yards of mining and milling wastes were delivered to the CFR-BFR confluence where the material was stopped by Milltown Dam. These and other contaminated materials delivered to the reservoir over the past ninety years, have polluted the surface and groundwater resources in the area (EPA, 2004).

By 1937, a state highway and the CMSPR had been added to the transportation corridor. The transportation corridor, primarily the state highway and the CMSPR, narrowed the CFR floodplain. The highway embankment to the north of the CFR and the railroad grade to the south of the river restricted the floodplain width upstream from the CFR-BFR confluence to 2,500 ft. River meanders were isolated by the fill slopes and the river length was shortened (see Figure E-1). The CFR floodplain was again narrowed by 400 ft to 500 ft to a floodplain width of 2,100 ft with the construction of Interstate 90. Truncated meanders, clearly observable today, are

disconnected from the main channel and floodplain, but capture groundwater and surface runoff. Although vegetation has encroached on the historical channel segments, the features largely retain the historical channel geometry and dimensions (see Figure E-6 and E-7).

D.3.3 Existing River Corridor Conditions: 1940 to Present

The existing river corridor conditions exhibit both the natural valley-floodplain-channel forms as well as over one hundred and fifty years of human-related land uses. Construction of Interstate-90, continued resource development, and an increasing human population have affected the CFR watershed. However, the cessation of large-scale mining, milling, and smelting operations in the CFR headwaters has dramatically improved air, water, and soil quality throughout the watershed. Comprehensive restoration efforts throughout the CFR and BFR drainages are in the process of rehabilitating ecosystems that were severely damaged by the long period of mining activities. With an increasing understanding of the role of the contaminated sediments in Milltown reservoir, the public has taken an increased interest in the CFR watershed. The RP is a representation of this interest and motivation to rehabilitate the CFR watershed.

D.3.4 Valley Morphology – The Role of Valley Morphology on the Historical, Existing, and Future Channel Planforms

Three valley types are found in the restoration project area. These valley types form a continuum from upstream to downstream and are characterized by degree of floodplain-river confinement. Valley types found in the restoration project area include Valley Type VIII (upstream of Duck Bridge), Valley Type II (CFR-BFR confluence area), and Valley Type IV (downstream from Milltown Dam through Bandmann Flats). The following section highlights the valley type characteristics and valley type-river interactions.

Prior to development, the valley upstream from Duck Bridge was as a Type VIII valley (Rosgen, 1996). Type VIII valleys are associated with multiple terraces in broad, moderate gradient valleys. Glacial Pleistocene terraces, adjacent lower elevation alluvial Holocene terraces and wide floodplains, are principal features of this valley type. In undisturbed conditions, terraces and floodplains are well-vegetated by a continuum of plants ranging from xeric species on drier terraces to mesic species on floodplains. Slightly entrenched, meandering channel planforms defined by riffle-pool bed morphology (C stream type) are the predominant channel type found in Type VIII valleys. Channels tend to laterally migrate across the floodplain expanse and create new floodplain surfaces while eroding old ones. In a natural state, the migrating channel will maintain the average hydraulic geometry as the channel transports its sediment load and conveys its discharge. Under altered conditions typified by channelization, riparian vegetation removal, or increased/decreased sediment delivery to the channel network, the channel may depart from dynamic equilibrium. Channel incision or braiding may occur in response to channel disturbances that affect stream energy, bank stability, and sediment particle distribution.

The valley and valley-channel interactions upstream from the Duck Bridge were modified by the encroachment of the transportation corridor on the river corridor. The narrowed valley bottom likely steepened the channel gradient are decreased the floodplain area available for floodwater and sediment storage. These modifications have caused the channel to transition from the likely

historical meandering channel planform, to a braided channel regime characterized by accelerated bank erosion, channel widening, and aquatic habitat impairment.

Type II valleys are characterized by stable, gently sloping hillsides and a moderately steep valley floor gradient (≤ 4 percent). Sediment sources are generated through channel derived alluvium and hillslope contributed colluvium. Typical channels draining Type II valleys are moderately entrenched, generally stable channels (B stream type). The channel is structurally controlled by lateral hillslopes and floodplain development is moderate with relatively narrow, sloping and well-vegetated floodprone areas.

Downstream from Duck Bridge, the historical CFR valley type was most likely a Type VIII valley transitioning into a Type II valley at the CFR-BFR confluence. The valley transition through the Duck Bridge area has been masked by sediment deposition in the reservoir. The BFR valley upstream from the confluence to beyond Stimson Dam is predominantly a Type II valley.

Valley Type IV resembles the characteristics presented for Valley Type II. Streams in Type IV valleys are confined by the valley margin and there is high valley-channel connectivity. However, Type IV valleys differ from Type II valleys in channel sinuosity and the degree of channel entrenchment. Type IV valleys tend to have steeper hillslopes that form a canyon or gorge-like feature. Valley floor gradients are minor, usually less than 2 percent. Riffle-pool bed morphology exists and depending on consolidation of hillslope materials, sediment supply is moderate to high. Within these valleys, confined channels (F stream type) predominate, but where floodplain development occurs, moderately entrenched riffle-pool channels (C stream type) channels may persist. The valley at the confluence (just upstream from Milltown Dam) and extending downstream from the railroad bridges is a Type II valley transitioning to a Type IV valley. A comparably unaltered Valley Type IV is located downstream from the I-90 bridge through Bandmann Flat.

Valley Type VIII, Valley Type II, and Valley Type IV have been found to support single thread, meandering channels in undisturbed watersheds. As natural river corridors are modified by human land uses, rivers may deviate from historical conditions. Varied inputs of sediment and discharge, changes in vegetation conditions, and anthropogenic channel modifications may cause a river to deviate from the range of historical channel conditions. Adjustment to changes in these variables may result in the river seeking a new equilibrium (Knighton, 1984).

Currently portions of the CFR study reach (CFR3-A and CFR3-C) are characterized by a braided planform. Most likely, this condition has endured since the flood of 1908. According to the research related to valley types and associated channel planforms, a braided channel planform in a Type VIII valley is indicative of a disturbed state (Rosgen, 1996). However, the braided channel is a naturally occurring stream pattern under certain conditions in specific valley types. The following section highlights valley types that are associated with braided channel planforms. The purpose of this discussion is to acknowledge that the following valley types are not found in the CFR near Milltown Dam, and therefore, CFR channel braiding is likely a result of river corridor modifications and channel disturbance.

Type III valley types are conducive to forming braiding patterns (D stream types) due to high sediment delivery and depositional regimes. Characteristic features of this valley type are alluvial fans and debris cones with moderately steep at valley gradients (≥ 2 percent). Mass movements or failures from adjacent hillslopes can act as transport mechanisms, delivering large volumes of sediment and woody debris to the active channel. Type III valley streams lack the stream power to efficiently route incoming sediment (mostly larger-sized particles). In addition to sediment delivery, channels in this valley type are also influenced by vegetation condition. Where thick, lush riparian vegetation exists, single thread channels can occur, but only if the reach is not depositional. Faulted valleys or valleys that are inclined as a result of structural faults traversing through the area are prone to braiding. Although the CFR study reach is depositional, mass earth and debris movements, hillslope failures, and colluvium are not a quantifiable portion of the sediment load. Further, the valley gradient in the CFR study reach is considerably less than the two percent valley slope associated with Type III valleys.

Valley Type IX is characterized by valleys in the glacial outwash plain. The braiding associated with active glaciers is the most prolific state amongst all depositional valley types. Glacial outwash streams are commonly braided with multiple diverging channels that are wide and shallow. High sediment load facilitates formation of many mid-channel bars of sand and gravel which become emergent at low to moderate discharges (Church and Jones, 1982; Hein and Walker, 1977). Highly variable discharges generate abrupt changes in particle size downstream from glaciers. Recent bedload deposits form easily erodible banks of sand and gravel as the absence of silts and clays result in low bank cohesion (Easterbrook 1993). Glacial outwash streams are associated with high rates of lateral migration, shifting channels and steep gradients (Easterbrook, 1993; Rosgen, 1996). In the Pleistocene ice ages, the CFR may have periodically existed as a Type IX valley. Modern climate regimes have formed a more steady state system with seasonal discharge patterns and reduced natural sediment loading relative to glacial periods. The last valley type associated with naturally braided channels is Valley Type XI. Valley Type XI braided channels are associated with river deltas where multiple water bodies converge. Categories of deltas and corresponding stream types that occur within them include propagating deltas, non-building deltas, and anastomosing deltas (Fischer et al., 1969; Rosgen, 1996). Propagating deltas are classified as elongate and lobate. Non-building forms of deltas are wave-dominated and tide-dominated, where oceans processes keep these forms from extending. Both propagating and non-building deltas display intricate distributary systems. Channels occurring within these deltas are dynamic (Easterbrook 1993). The anastomosing delta is characterized by multiple branching channels with stable well-vegetated islands and extensive wetlands. Valley Type XI morphology is not found in the CFR near Milltown Dam.

To conclude, three valley types were identified in the restoration project area. The valley types are associated with single thread meandering channels and typically do not support braided channel regimes unless fluvial processes have been modified by land management practices. Three other valley morphologies typically associated with braided channel regimes were also presented. These valley morphologies were not identified in the CFR near Milltown Dam, further suggesting that channel braiding in the CFR is associated with land management practices and the resultant channel response.

D.3.5 Time Series Aerial Photograph Interpretation

Time series aerial photographs were reviewed to characterize river planforms for the CFR in the restoration project area and in upstream reaches, as well as on the BFR in the Ovando Reach. This effort was completed to determine historical and recent planforms, channel alignment changes over time, and to provide design criteria for the CFR channel in the restoration project area. The following sections present the results of the aerial photo interpretation.

D.3.5.1 Planform Belt Width Analysis Results

A planform belt width analysis was completed for the study area (see Appendix E for photo panels). The purpose of the analysis was to ascertain trends in the planform belt width both spatially and temporally within CFR study reach. It was also used to assess channel planform differences as they relate to impacted and functioning channel locations. Reference planform dimensions measured on relic channel features were compared to active channel reaches.

Two extensively braided reaches from station 180+00 through 230+00 and station 270+00 through 330+00 (Figure D-2) were identified and displayed the largest belt width within the study area. Conversely, the channel belt width was at a minimum where the transportation corridor narrowed the valley bottom at station 230+00 through 270+00 and station 330+00 through 390+00. Intermediate belt widths were measured where a single thread channel occupied a wider portion of the floodplain (station 140+00 to 180+00). This section of channel also exhibited the greatest belt width variation. Channel planform for a particular reach generally remained consistent over time— a braided reach tended to remain a braided planform (station 180+00 through 230+00), while meandering reaches maintained single thread channels (station 140+00 through 180+00) over the time series. However, several areas also exhibited trends towards a single thread channel with vegetation recovery following periodic large magnitude floods.

Historical meander scrolls identified in the CFR near Milltown Dam in the 1937 floodplain (station 215+00 through 250+00), likely represented a pre-disturbance condition and were found to have belt width dimensions similar to the CFR3-B reference reach. Additional abandoned meanders identified within the active 1937 floodway (station 130+00 through 150+00 and station 155+00 through 160+00), also displayed a range of intermediate belt width values.

Belt widths measured on the CFR near Clinton were found to have higher values than the downstream CFR3-B and historical meander values, but belt width values were less than the values measured in the braided reaches. The Ovando C reference reach also exhibited intermediate belt width values.

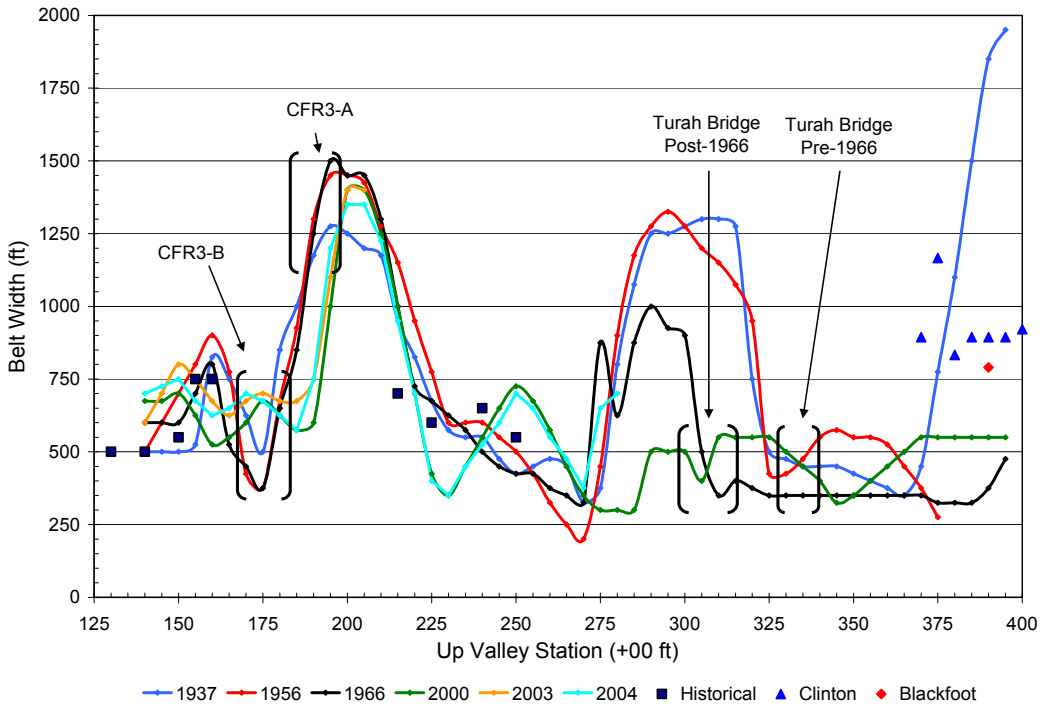

Figure D-2. Planform belt width by photograph series through the CFR3 study area. Comparative points are also presented for the Clinton Reach and the Ovando C Reach.

D.3.5.2 Historical Channel Sinuosity Analysis

Similar to meander belt width, channel sinuosity varied throughout the CFR near Milltown Dam and was generally related to the valley bottom width as influenced by the transportation corridor (see Appendix E, Figures E-5 to E-10). Table D-1 summarizes channel sinuosity for each of the four photo plates. Plate 5 (Figure E-7) exhibits the largest variation in channel sinuosity through time; from a high of 1.33 in 1966 to 1.09 in 2004. Plate 5 includes the CFR3-B reference reach. A decline in sinuosity is evident from 1937 to 1956 from 1.27 to 1.23, respectively. By 1966, sinuosity had increased to the highest value (1.33) within the study area since 1937. The time interval from 1966 to 2000 (34 years) displays the greatest decline; from the high of 1.33 to 1.14. By 2003, sinuosity within Plate 5 had reached a minimum of 1.09. Channel migration within a consistent belt width is prevalent in Plate 5.

Plate 6 exhibited the lowest variability in channel sinuosity with values ranging from 1.05 to 1.03. The majority of the river channel in this reach is braided and interacts with the southern railroad grade. In the downstream portion of Plate 6, channel sinuosity increases as the channel trended away from the railroad grade over time. However, as shown in the 2003 and 2004 photos, the dominant channel relocated to the toe of the grade.

Plate 7 captures the CFR transitioning from the northern valley boundary to the southern railroad grade. Sinuosity ranges from a high of 1.28 in 1937, to 1.17 in both 1956 and 1966. By 2000, channel sinuosity increased to 1.23. Although channel migration is limited by the I-90 fill slope to the north as well as the Turah Bridge in the middle of Plate 7, the CFR has occupied several channel locations across the floodplain in this reach.

Plate 8 contains the lowest sinuosity in the study area. Sinuosity values range from a maximum of 1.05 in year 2000 to a minimum of 1.00 in 1966. The CFR in this reach follows the I-90 fill slope and may also be influenced by the Turah levee. The simplified channel is unlikely to change significantly in the future due to the lateral confinement of the reach.

Channel sinuosity was also measured on historical meander scrolls on Plate 5 and Plate 6 of the 1937 photograph series. Relic channel sinuosity was generally greater than contemporary channel sinuosity measured on later air photos. Relic channel sinuosity ranged from 1.33 to 1.21 on Plate 5 and Plate 6, respectively. Channel sinuosity measured on the CFR near Clinton, was 1.23. Sinuosity measured on the BFR Ovando C reference reach was 1.29.

Table D-1. Channel sinuosity by photo plate and time series photo year. Relict channels measured on Plate 5 and Plate 6 are also presented.

Time Series	Photo Plate 5	Photo Plate 6	Photo Plate 7	Photo Plate 8	Relict Channels (Plate 5)	Relict Channels (Plate 6)	Clinton Reference	Ovando C Reference Reach
1937	1.27	1.05	1.28	1.01	1.33	1.21	1.23	1.29
1956	1.22	1.05	1.17	1.04				
1966	1.33	1.04	1.17	1.00				
2000	1.14	1.04	1.23	1.05				
2003	1.09	1.03						
2004	1.09	1.03						

In general, channel sinuosity has decreased over time in the CFR near Milltown Dam. A trend of channel straightening is most pronounced in Plate 5 while the CFR in Plate 8 has been straight since the earliest aerial photo. Relic channels in Plate 5 and Plate 6 as well as the Clinton and Ovando C reaches exhibited greater channel sinuosity than much of the CFR in the study reach. Channel length in the study area has been limited by the I-90 fill slope on the northern boundary of the river and the CMSPR railway bed on the southern boundary of the channel alignment.

D.4.1.3 Meander Geometry Reference Conditions

An analysis was completed to assess CFR reference planform geometry by referring to the un-impacted channel planform in four locations. Measurements were completed on planform segments that reflected modern day (Holocene) CFR flow regimes. Additionally, selected planform segments displayed minimal impacts and retained meandering planform morphology. CFR results were also compared to results for the BFR Ovando C reference reach.

Average CFR meander belt width ranged from a minimum of 608 ft to a maximum of 928 ft (Table D-2). The historical scrolls represented minimum values while the Clinton reach contained maximum average values. Similar belt width results were noted between the BFR Ovando C reach and the 1937 CFR3-B reference reach, 790 ft and 825 ft, respectively. The 2004 CFR3-B reference reach and the remnant channel segments also displayed similar belt width values, 608 ft to 618 ft, respectively. The Clinton reach had a belt width of 928 ft.

Table D-2. Mean values for meander length, belt width, and radius of curvature measured in and outside of the restoration project area.

Reach	Meander Length (ft)	Belt Width (ft)	Radius of Curvature (ft)
Remnant Channel Segments	2,111	617	580
1937 CFR3-B Reach	1,725	825	372
2004 CFR3-B Reach	2,150	608	656
Clinton Reach	2,797	928	701
Ovando C Reach	1,708	790	437

A similar range of values is evident with radius of curvature. Minimum values are associated with the 1937 reference reach (372 ft). Maximum values were measured in the Clinton reach (701 ft). The BFR Ovando C reach compares to the CFR 1937 CFR3-B reference reach (372 ft and 437 ft, respectively). The historical scrolls and the 2004 CFR3-B reference reach display radius of curvature measurements of 580 ft and 658 ft, respectively. The Clinton reach again occurs as a maximum, 701 ft, but does compare with the 2004 CFR3-B reference and historical reaches.

Meander wavelength exhibited trends similar to those identified for belt width and radius of curvature. The range of values indicates a minimum of 1,708 ft at BFR Ovando C reach and a maximum in the Clinton Reach, 2,797 ft. The historical traces compare closely to the 2004 CFR3-B reference reach, 2,150 ft and 2,111 ft respectively. The 1937 CFR3-B reference reach and the BFR Ovando C reach are comparable 1,725 ft and 1,708 ft, respectively. The Clinton reach displays a substantially greater value than the other reference conditions, 2,797 ft.

The measured planform geometry variables were divided by the appropriate bankfull channel width to develop dimensionless ratios (Table D-3). Analysis of the belt width demonstrates continuing comparison between the historical channel segments and the 2004 CFR3-B reach. However, the 1937 CFR3-B belt width values were similar to the Clinton reach results, where as the measured numbers suggested a divergence. The BFR Ovando C reach, related to belt width dimensionless coefficient was an intermediate value of 4.9. Alternately, the average belt width dimensionless coefficient value for the Clinton reach was within the range of the CFR3-B results.

Radius of curvature dimensionless coefficients were similar for the remnant channel segments, the 2004 CFR3-B reach, and the Clinton reach, spanning from 4.2 to 4.8. Identical dimensionless ratios (2.7) were recorded for the 1937 CFR3-B and the BFR Ovando C reach.

Dimensionless ratios for meander wavelength were more varied. The remnant channel segment and the 2004 CFR3-B reach had similar dimensionless values of 15.7 and 15.4, respectively. The 1937 CFR3-B had a consistent dimensionless value of 15.7, while the Clinton reach and BFR Ovando C reach formed the upper and lower limits of the dimensionless coefficient meander wavelength range, 17.5 and 10.7, respectively.

Table D-3. Dimensionless coefficients for meander length, belt width, and radius of curvature measured in and outside of the restoration project area.

Reach	Dimensionless Meander Length	Dimensionless Belt Width	Dimensionless Radius of Curvature
Remnant Channel Segments	15	5	4
1937 CFR3-B Reach	13	6	3
2004 CFR3-B Reach	16	4	5
Clinton Reach	17	6	4
Ovando C Reach	11	5	3

D.3.5 Comparison of the CFR-BFR Confluence to Other River Confluences in Western Montana

Five river confluences in western Montana were reviewed to investigate river planform in the vicinity of confluences. Table D-4 includes data for the five confluences that were reviewed. The BFR/CFR river confluence is shown as the first line in the table from which to compare the remainder of the examples. If the river reach is in transition, it is indicated as a trend in the downstream direction. Column 7 is the determination of whether the river is braided (B), meandering (M), or anabranching/wandering (A).

Table D-4. Summary of river confluence data from confluences in western Montana.

River Confluence (River 1/River 2)	Valley 1 Gradient (ft/ft)	Valley 2 Gradient (ft/ft)	Valley 1 Type	Valley 2 Type	Valley type after Confluence	River Morphology
CFR/BFR near Milltown	0.0030	0.0020	VIII	II	II to IV	Reservoir
NF Flathead/MF Flathead near Columbia Falls	0.0025	0.0025	VIII	II	VIII to II	M
CFR/Flathead near Paradise	0.0010 - 0.0020	<0.0020	VIII	II or IV	VIII to II	M
CFR/Rock Creek near Clinton	0.0035	0.0034	VIII *	VIII	VIII *	M
BFR/NF BFR near Ovando	0.0030	0.0030	VIII to II	VIII	II to VIII	M

Table D-4 (Continued). Summary of river confluence data from confluences in western Montana.

River Confluence (River 1/River 2)	Valley 1 Gradient (ft/ft)	Valley 2 Gradient (ft/ft)	Valley 1 Type	Valley 2 Type	Valley type after Confluence	River Morphology
CFR/Bitterroot near Missoula	0.0020	0.0010	VIII *	VIII	VIII	CFR A-B, BTR M, CFR M downstream

*: These river segments are highly modified due to development or transportation corridors. Direct channel modifications, including straightening, oxbow cut off, widening are apparent in the aerial photographs.

The North Fork Flathead River-Middle Fork Flathead River near Columbia Falls, and the Clark Fork River-Flathead River near Paradise are presented for discussion. These two confluences are included as the second and third confluences in Table D-2.

The North Fork Flathead River-Middle Fork Flathead River confluence is geomorphically similar to the CFR-BFR confluence. The North Fork Flathead is a Type VIII valley similar to the CFR upstream from the confluence. The Middle Fork Flathead is a Type II valley, similar to the BFR. Downstream from the confluence, both rivers transition into a more confined valley type. Both confluences are low gradient, alluvial, gravel bed rivers with numerous impacts and disturbances upstream. The Flathead system has had several large floods over the past four decades. As indicated in Figure D-3, both forks of the Flathead River currently have meandering morphology that continues downstream.

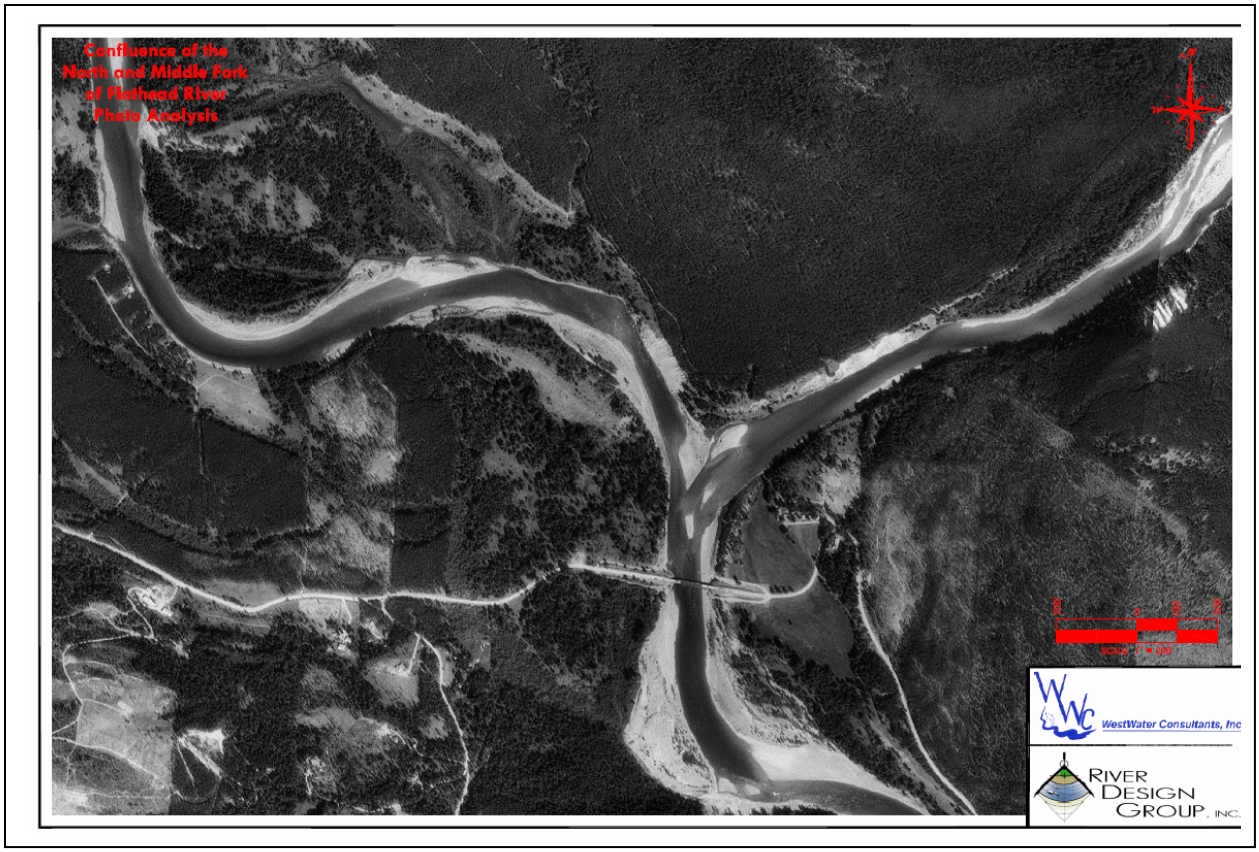

Figure D-3. Confluence of the North Fork Flathead River with the Middle Fork Flathead River near Columbia Falls, MT.

The confluence of the Clark Fork River with the Flathead River is another example of similar rivers converging without apparent braiding or anabranching (Figure D-4). Like the previous example, both rivers are low gradient systems with the Flathead River located in a large, unconfined valley while the CFR is moderately confined. Downstream of the confluence, the CFR transitions to a moderately confined valley type. Both rivers have numerous impacts upstream and have experienced large floods over the last several decades.

Three other river confluences were also reviewed, including the CFR and Rock Creek confluence; the Blackfoot River and North Fork Blackfoot River confluence; and the CFR and Bitterroot River confluence. The CFR at both the Rock Creek and Bitterroot River confluences indicates a highly modified channel with oxbow cut-offs, channel straightening, bridges and other direct modifications in the immediate upstream segment. Both river confluences occupy Type VIII valleys, although the floodplain widths are much less than historical conditions prior to transportation corridor development. At the Rock Creek confluence, the CFR maintains a meandering planform in spite of the direct impacts. At the Bitterroot River confluence, the CFR is heavily modified as it flows through Missoula. At the confluence, the CFR exhibits an anabranching to braided morphology similar to the braided reaches of the CFR in the project area. The North Fork Blackfoot River is a meandering river in a Type VIII valley upstream from the confluence with the BFR, which is in a Type II valley. Floodplain gradients and

morphologies are similar to the CFR-BFR confluence in the project area. Both rivers maintain a meandering planform through the confluence reach.

While this analysis is not definitive as to the morphology the CFR and BFR confluence, several examples of similar, meandering river confluences are available to validate the basic concept that meandering river systems can converge and remain stable over time.

Figure D-4. The confluence of the Clark Fork River and Flathead River near Paradise, MT.

D.3.6 BFR Floodplain Transition Analysis Results

The BFR floodplain transition analysis was completed to investigate floodplain-channel relationships relative to a valley transition. The Ovando reach was selected as an analog for the historical CFR valley transition that occurred from upstream of the Duck Bridge, through the Milltown Dam site, to Bandmann Flats. Channel morphology variables were plotted against valley stationing to evaluate trends related to the valley transition. Graphs exhibiting trends between the channel planform variable and valley stationing are presented. Table D-5 includes the descriptive statistics for the channel planform geometry variables.

Table D-5. Channel planform geometry variables for the three stream types in the valley transition reach.

Stream Type	Meander Length (ft)	Radius of Curvature (ft)	Belt Width (ft)	Floodprone Width (ft)
C Reach	1,688 (1003 - 2,407)	408 (133 - 690)	769 (401 - 1,203)	734 (560 - 1,120)
B Reach	1,555 (1,505 - 1,605)	1,906 (1,805 - 2,006)	376 (351 - 401)	511 (420 - 600)
F Reach	2,207 (1,505 - 2,909)	548 (313 - 564)	589 (502 - 702)	430 (200 - 800)

The meander wavelength generally increased in a downstream direction from the C stream type to the F stream type (Figure D-5). While the BFR in the C channel reach was free to laterally migrate, the F channel reach was structurally controlled. The distance between consecutive meanders increased as the channel was increasingly confined by the valley as the valley transitioned from a Type VIII valley a Type II valley to a Type IV valley.

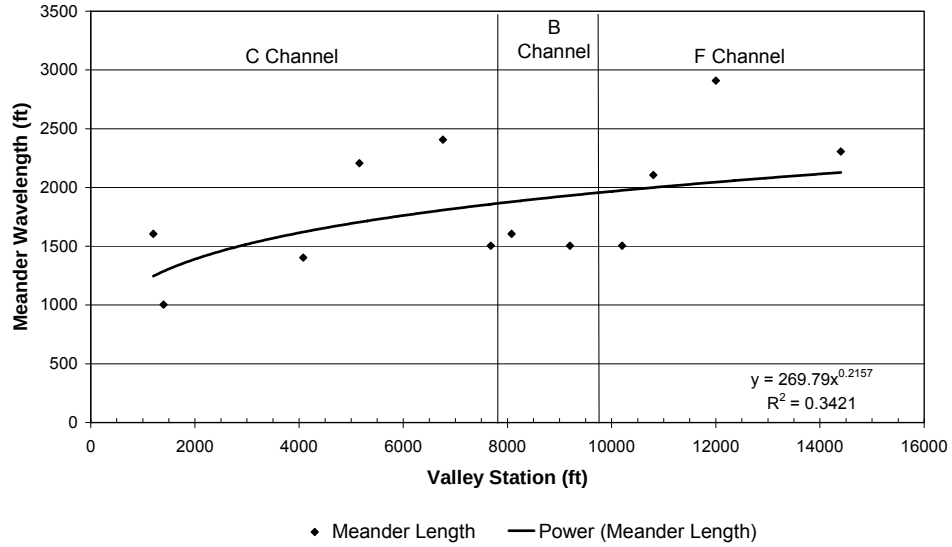

Figure D-5. Meander wavelength relative to valley stationing and stream type for the BFR Ovando reference reach.

Radius of curvature remained fairly consistent through the transition except for in the B stream type reach. Tighter radii were noted in both the upstream C reach and the downstream, entrenched F reach. Maximum variation occurred in the C reach as the system meanders through the available floodplain. Downstream within the F reach, the meander cycles are structurally controlled and exhibit less variation than the upper reach, but more than the transition reach. The transition reach is relatively short, 2,300 ft, and only includes two meanders which have a similar radius.

The floodplain area as measured by the floodprone width also exhibited a down-valley trend. As the BFR transitioned from the unconfined Type VIII valley in the C reach to the structurally controlled Type II valley in the F reach, the floodprone width narrowed. This morphological trend was expected based on the valley types. However, instead of a smooth, consistent narrowing of the floodplain through the B transition reach and into the entrenched F reach, the floodplain widens substantially at the beginning of the B and F reaches (Figure D-6). The data

points illustrate this condition with a momentary increase in floodplain width at each transition, then narrowing again in the downstream direction. Meanders occur at each of these transitions and may encourage flooding of the opposite bank during high flows.

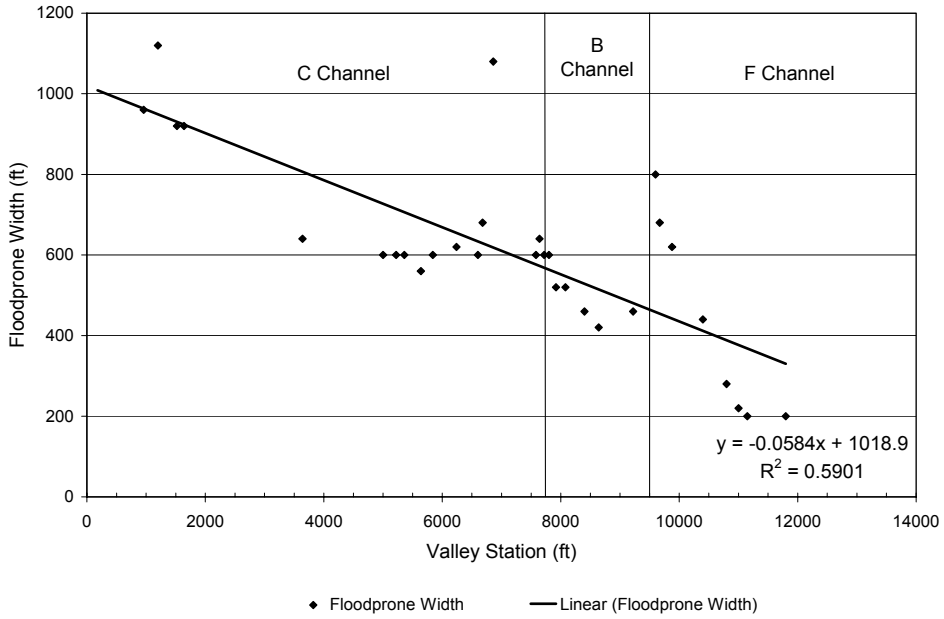

Figure D-6. Floodprone width relative to valley stationing and stream type for the BFR Ovando reference reach.

There was also a notable increasing trend in the riffle width-to-depth ratio in a down-valley direction (Figure D-7). As the floodplain narrows width-depth ratios increase. Lower values occur upstream in the C reach and maximum values occur downstream in the F reach. The transitioning B reach was characterized by intermediate width-to-depth ratio values. Although a relatively strong trend was detected, substantial variation in width-to-depth ratio exists within each reach. The channel width-to-depth ration likely relates to the influence of flood flows that scour the channel. In the slightly confined C reach, flood flows access the adjacent floodplain and the stream energy is dissipated. In the entrenched F reach, flood flows are maintained within the active channel and there excess stream energy available to scour the channel.

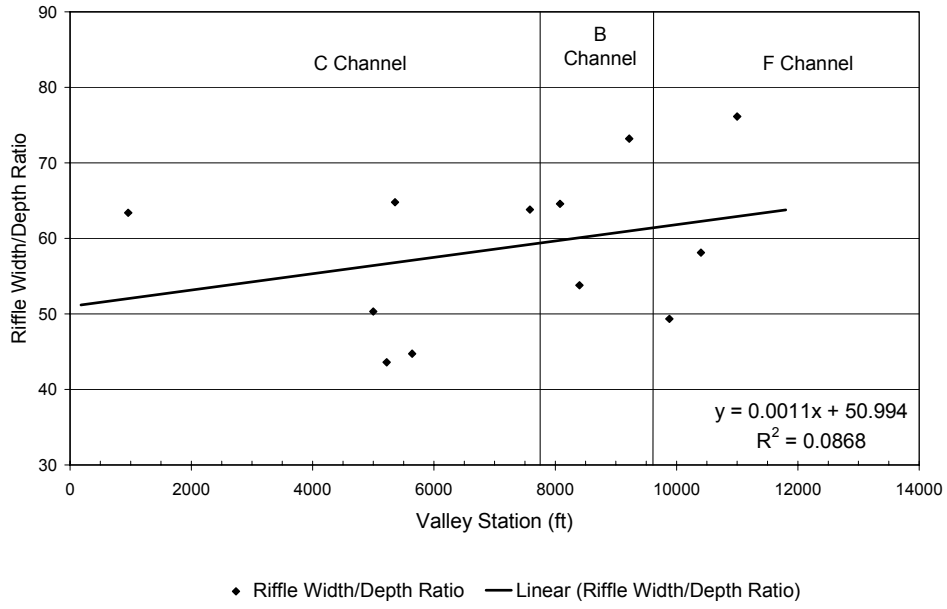

Figure D-7. The riffle width-to-depth ratio relative to valley stationing and stream type in the BFR Ovando reference reach.

Pool spacing increased in the downstream direction through the valley transition suggesting greater stream energy in the confined F reach (Figure D-8). The shortest spacing was observed in the upstream meandering C reach where nine pools occurred, and minimum values obtained in the downstream F reach where two pools exist. Within the transition B-reach, one pool was noted.

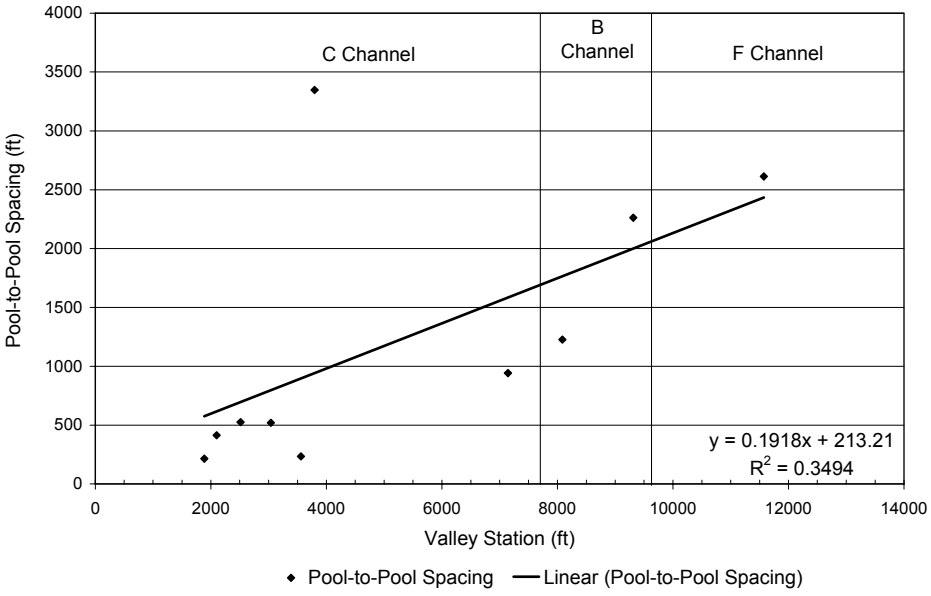

Figure D-8. The pool-to-pool spacing as measured by the distance between pools, relative to valley stationing and stream type in the BFR Ovando reference reach.

Channel sinuosity, channel slope, and the riffle D_{50} particle size were also evaluated relative to valley type (Table D-6). The channel sinuosity decreased from the C reach to the downstream F reach as the BFR transitioned from a slightly confined to an entrenched system. As the system transitions from a laterally migrating channel to a structurally controlled channel, the BFR becomes limited in its ability to adjust its channel dimensions and location. Based on the decrease in sinuosity in the Type IV valley (F reach), it would be expected that the valley slope would have been steeper to account for the lower sinuosity. The valley slope steepens at the transition reach, but then flattens in the F reach to near the C reach slope. Water surface slope transitions similarly to the valley slope, but the differences are greater due to the decreasing sinuosity (valley slope/sinuosity = water slope). The water surface slope transitions from 0.0023 in the Type VIII valley, to 0.0029 in the transition valley, to 0.0025 in the Type IV valley.

Table D-6. Channel sinuosity, slope, and the riffle D_{50} particle size results for the valley transition.

Reach	Channel Sinuosity	Valley Slope (ft/ft)	Water Surface Slope (ft/ft)	Riffle D_{50} (mm)
Type VIII – C Reach	1.29	0.0030	0.0023	53.5
Transition – B Reach	1.16	0.0034	0.0029	77.8
Type IV – F Reach	1.14	0.0029	0.0025	75.0

The riffle D_{50} particle size increased through the valley transition, indicating an increase in stream power from the C reach to the B reach. The D_{50} particle size decreased slightly from the B reach to the F reach, but remained similar suggesting similar stream power.

D.4 DISCUSSION

The following sections summarize the valley and floodplain morphology analyses that were completed to characterize the historical and existing river corridor conditions, in addition to facilitating planning for the CFR restoration project area.

Analysis of historical narrative, maps, and aerial photographs suggest that the CFR valley has undergone widespread changes since the first homesteads were established in the valley in the 1850s. Mining impacts, construction of the transportation corridor, and other watershed development sensitized the CFR prior to the 1908 flood of record. Accelerated sediment delivery to the channel network combined with floodplain grazing and a constricted valley bottom likely accentuated the flood effects. The location of the recently completed Milltown Dam at the confluence of the CFR and BFR created a bottleneck in the river corridor. The southern portion of the cribwork was blown up in a successful attempt to preserve the remaining structure and the valuable electricity-generating turbines. With the recession of the floodwaters, the damage to the CFR upstream from the dam was apparent. Several million yards of mining debris had deposited in the reservoir, greatly reducing the reservoir capacity shortly after the completion of the dam. Continued watershed development further affected river integrity.

Human modification of the watershed has played an important role in the physical, chemical, and biological processes of the CFR. A temporal pattern of channel planform conditions was identified during the time series air photo analysis. It was determined that the river exhibited a

temporal cycle related to large scale flood events. The channel typically widened and braided following large flood events. However, between flood events, the channel narrowed as riparian vegetation colonized disturbed areas and floodplain deposits. Although this pattern was repeated over time in several locations, it was also apparent that some reaches maintained consistent planforms over time. For example, the CFR3-B reference reach has exhibited the greatest resistance to channel braiding. The upstream portion of the CFR3-B reference reach has remained relatively unchanged through the past nearly 70 years. Reasons for this could be the stabilizing effects of mature vegetation, a resistant terrace reinforced by the rail road grade, or a more expansive floodplain relative to other reaches. In contrast to the dominant channel trend in CFR3-B, CFR3-A has remained extensively braided over time. Although the main channel and secondary channels have shifted and rerouted, the general braided planform has not changed. A consistent supply of sediment delivered from upstream reaches and also scoured from the channel adjacent to the highway embankment and railroad grade encroachments, maintains the braided planform. Accelerated sediment delivery is expected to continue as a headcut advances upstream.

Planform geometry analysis results suggested that floodplain infrastructure, primarily the I-90 embankment and the CMSPR railway grade, influence planform geometry throughout the restoration project area as well as in the CFR upstream study area. Remnant channel segments, the CFR3-B reference reach, and the BFR Ovando C reference reach generally displayed similar intermediate values for planform geometry variables. Conversely, CFR reaches in the vicinity of the I-90 embankment (Figure E-10, upstream from Turah Bridge) or the railroad grade (Figure E-9, CFR upstream study reach) exhibited lower sinuosity, greater meander length, and greater radius of curvature. In short, the CFR in these reaches tended to be straight and interacted with the interstate or railroad grade fill slopes.

Channel belt width values also corresponded to the channel's proximity to the transportation corridor. Braided reaches were typically located where the channel is unconfined. Braided sections tended to be located downstream from confined reaches where the channel interfaced with an embankment. In these confined sections, the channel is likely more competent in transporting sediment. The more efficient sediment transport delivers bedload to the downstream unconfined reach that is characterized by lower competence. Channel aggradation in these reaches leads to channel widening, bank failure, and continued braiding. Braided reaches had the highest belt width values. Alternatively, the lowest belt width values were measured where the transportation corridors encroached on the CFR, resulting in channel entrenchment and minimal lateral channel migration. The repeating pattern of a reach with a narrow belt width followed by a reach with a wide belt width corresponded to a confined reach with excess sediment transport capability followed immediately by an unconfined reach where deposition and braiding occurred. This pattern has been noted on other western rivers where transportation corridors or other channel straightening has occurred. In contrast to these conditions, the BFR near Ovando, which has not been subjected to extensive channel modifications, is a relatively stable meandering channel without this repeating scour-deposition pattern.

The BFR Ovando reference reach provided insights on the influence of valley morphology on the floodplain-river environment. The Ovando reach is characterized by a valley transition that

trends from a slightly confined Type VIII valley to a confined Type IV valley. Floodplain width and channel morphology variables responded to the narrowing valley bottom and reduced floodplain width. The strongest valley transition-channel morphology relationship was the floodprone width versus the down-valley stationing. Moving downstream, the floodprone area narrowed as the valley walls encroached on the floodplain. Through the valley transition the floodplain tended to decrease its width by about 0.06 feet per foot of down-valley distance (1 foot of floodprone width decrease for every 16.7 feet of down-valley direction). These valley-floodplain-channel morphology relationships will be further investigated during the Phase 3 design.

Ideally, the restoration design would attempt to restore the CFR and BFR to their historical condition. However, the restoration design must account for existing conditions, channel potential given the watershed conditions, and the constraints presented by infrastructure within the project area. Based on this analysis the CFR upstream from the confluence appears to have been a meandering channel with a broad, well-vegetated floodplain. The historical channel planform geometry was likely characterized by moderate sinuosity and belt width. Construction of the transportation corridor and Milltown Dam in the late 1800s and early 1900s modified the CFR valley and river. Existing channel planform geometry values now reside at two extremes according to the channel's location relative to the transportation corridor. A limited number of reaches continue to express the historical channel planform.

Historically, as the CFR approached the BFR confluence, Holocene and Pleistocene terraces constricted the floodplain resulting in a narrowed channel belt width and decreased sinuosity. Valley gradient appears to have remained relatively constant through this transition. Downstream from the confluence, in the vicinity of the Milltown Dam, the floodplain continued to narrow due to lateral confinement by the terraces and rock outcrops until the lower CFR transitioned to a confined system. The historical BFR channel exhibited a similar channel planform upstream from the CFR confluence. Development in the confluence area and the construction of Milltown Dam modified the historical CFR and BFR planforms and fluvial processes.

Restoration project area constraints will limit the potential full expression of the CFR planform upstream from the confluence. Lateral channel migration will be limited where contaminated sediments are to be left in-place. Stabilizing the contaminated sediments mandates that the restored river be relatively stable in the short-term (20 to 30 years) until riparian vegetation colonizes and naturally stabilizes the floodplain. Also, most objectives listed in the RP would be defeated or achieved to a lesser degree by a braided channel system, including providing channel stability; facilitating sediment transport; hastening vegetative recovery; improving aquatic habitat and water quality; and increasing recreational opportunities.

It is unlikely that the system can be restored to its historical conditions due to past and contemporary disturbances. However, the preceding analysis indicates that a meandering, single thread planform for the CFR upstream from the confluence would be the preferred planform. While accounting for existing infrastructure, the CFR and BFR in the restoration project area could be restored to near historical conditions with careful planning. Based on this analysis, a meandering C4 stream type transitioning to a B3c stream type is proposed for the CFR upstream

from the confluence. A B3c stream type should be constructed from the confluence downstream through the Milltown Dam site. The channel should transition to a F3 stream type downstream of the BNSF railroad bridge.